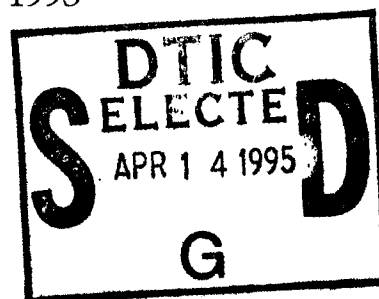


AOARD REPORT

Visit to the Minister of Int'l Trade and Industries' (MITI's)
Electrotechnical Laboratory (ETL) on 25 Oct 1993

Oct 25 93
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AOARD



This trip report discusses high power laser research being carried out at Optoelectronics Division of the Minister of International Trade and Industry's (MITI's) Electrotechnical Laboratory (ETL) for the generation of coherent soft x-ray radiation based on interactions of intense ultrashort-pulse lasers with rare gases. Over the past few years, ETL researchers have performed experiments to find out mechanisms associated with interactions of ultrashort-pulse lasers with rare gases. Experiments were performed using a femtosecond Ti:sapphire laser. The latest experimental results, as reported in LEOs '93, showed the observation of the 103rd harmonics order (7.6nm) in helium and the 95th harmonics order (8.2nm) in neon at laser intensities above 1015 Watts/cm².

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Subject: Trip Report - Visit to the Minister of International Trade and Industries' (MITI's) Electrotechnical Laboratory (ETL) on 25 Oct 93

Abstract

This trip report discusses high power laser research being carried out at Optoelectronics Division of the Minister of International Trade and Industry's (MITI's) Electrotechnical Laboratory (ETL) for the generation of coherent soft x-ray radiation based on interactions of intense ultrashort-pulse lasers with rare gases. Over the past few years, ETL researchers have performed experiments to find out mechanisms associated with interactions of ultrashort-pulse lasers with rare gases. Experiments were performed using a femtosecond Ti:sapphire laser. The latest experimental results, as reported in LEOs '93, showed the observation of the 103rd harmonics order (7.6nm) in helium and the 95th harmonics order (8.2nm) in neon at laser intensities above 10^{15} Watts/cm².

Introduction:

Headed by Dr. Kenzo Miyazaki, section chief of Laser Section, Optoelectronics Division, Electrotechnical Laboratory (ETL) of the Minister of International Trade and Industry (MITI), basic experimental research is carried out to investigate interactions of rare gases with intense ultrafast laser pulses. Laser pulses used in experiments are on order of subpicoseconds to femtoseconds at intensities in excess of 10^{13} - 10^{15} watts/cm², at values where the electric field becomes comparable to or in excess of the typical atomic Coulomb fields of 10^8 - 10^9 volts/cm. At these high electric field intensity levels, nonlinear interactions play an important role in determining the generation of higher orders of harmonics radiation. There has been a significant interest in this phenomenon because the experimental results suggest a promising approach to develop tunable coherent radiation sources in ultraviolet and soft x-ray spectrum regions.

The ETL group has thus far investigated interactions of femtosecond dye(616nm), XeCl (308nm), and Ti:sapphire (782nm) lasers with helium and neon gasses. The highest-orders (wavelength) of harmonic radiation obtained with a dye laser system were the 41st (15.0nm) in He, the 37th (16.6nm) in Ne, the 18th (32.4nm) in Ar, the 17th (36.2nm) in Kr and the 13th (47.4nm) in Xe. In a XeCl laser system, the 15th (20.5nm) in He, the 13th (23.7nm) in Ne, and 9th (34.2nm) in Ar, Kr and Xe were observed. In a Ti:sapphire laser system, the 103rd (7.6nm) in He and the 95th (8.2nm) in Ne were observed. Compared to other researchers in the world, their effort fall a bit short of the highest orders reported of the 109th (7.4nm) for Ti:sapphire and the 135th (7.8nm) for Nd:glass by J.J. Macklin et al (1993) and A.L. Huillier et al (1993), respectively.

Description of Dye, XeCl and Ti:sapphire Laser Systems Developed at ETL:

For dye and XeCl laser systems, a cw mode-locked Nd:YAG laser which produces 100-ps pulses is used as a master oscillator. The Nd:YAG laser pulses are compressed to a few psec by a fiber-grating compressor and frequency doubled in a KTP crystal. The frequency doubled (532nm) pulses are used to pump a synchronously-mode-locked linear cavity dye laser for the production of ~500 fsec pulses. The central wavelength of the dye

laser output is tuned to 616nm. The dye laser pulses are compressed to ~100fsec by a fiber-prism compressor and directed to the three stage amplifiers. On the other hand, a small portion of the master oscillate out is amplified by a regenerative Nd:YAG laser amplifier operating at 10 Hz. A single amplified pulse is extracted from the amplifier and further amplified by an Nd:YAG laser power amplifier. The Nd:YAG laser output is frequency doubled to pump three stage dye laser amplifiers. The maximum dye laser output energy is 2 mJ in 800 fsec pulses.

For the generation of fsec ultraviolet (UV) laser pulses, the dye laser output is frequency doubled in a 0.5 mm thick BBO crystal. The 308 nm radiation is separated from the visible one by a dichroic mirror and spatially filtered with a 0.2 mm diameter aperture. The UV seed pulse of about 50~100 micro joules is amplified in a commercial discharge XeCl excimer laser having tilted windows. The amplifier pulse energy is 3~5 mJ with a beam size of 1.0 cm². The output from the amplifier is spatially filtered with a 0.1 mm diameter diamond aperture in vacuum. The amplified beam is enlarged to match with a 2x2 cm² discharge cross section of the second XeCl laser amplifier. The output of the second XeCl amplifier produces a 30 mJ pulse at a repetition of 10 Hz. The amplified UV laser pulsewidth was measured to be 380 fsec by the background-free autocorrelation method using the third and fifth harmonic generation in a rare gas jet.

The Ti:sapphire laser system is configured similar to the one reported in Sullivan's paper, which came out in the journal, Opt. Lett. 16, 1406, 1991. It uses a cw mode locked Ti:sapphire laser oscillator, purchased from Spectra Physics and identified as Model 3960. The oscillator is pumped by another Spectra Physics laser, Model 2040E, which produces ~ 10nJ, ~80 fsec pulses at 82MHz. The output of the mode locked Ti:sapphire laser oscillator is amplified using the chirped pulse amplification technique. The femtosecond pulses are stretched to about 200 psec by a pulse stretcher which consists of a grating, an achromatic lens, and a total reflector. The stretched pulse is amplified in three stage Ti:sapphire amplifiers which are longitudinally pumped by the frequency doubled output of a Q switched Nd:YAG laser, operating at 10 Hz with a pulse energy of 0.8 joules. After a four pass amplification in the first amplifier, a single pulse is extracted from the pulse train by a Pockels cell pulse selector. After passing through a Faraday isolator, the single pulse is amplified by the second and third amplifiers where both of them are arranged for a two pass amplification. The pulse energy from the third amplifier is 70 mJ. Then the output beam of ~5 mm diameter is expanded to about 20 mm to prevent optical elements from damaging. The amplified pulse is recompressed in a pulse compressor to 200 fsec with an energy of 30 mJ. The central wavelength of the output is 782 nm with the full-maximum-half-width of 6 nm +/- 0.3 nm.

Harmonic Radiation Detection System:

It is important to find out how the harmonic orders are detected in their experiments to assure the reliability of their collected data. They use two detection devices to take data at two different spectral regions. For one detection device, the harmonic radiation in the spectral region of less than 70 nm is detected by a windowless Cu-BeO electron multiplier (EM:Hamamatsu, Model R595) mounted on a 1-m grazing incidence monochromator (Minuteman, Model 310-G) with an Au-coated 600 grooves/mm grating.

The second detection device, which detects wavelengths between 35 and 210 nm, is configured with another 20cm focal length very ultraviolet (VUV) monochromator (Acton, Model VM-502), having an Ir-coated 1200 grooves/mm grating, in addition to attaching EM and solar-blind CsI photomultiplier on each of two exit slits of the monochromator.

To assure the proper calibration of a detection system over the entire spectral region, ETL used a theoretical diffraction efficiency for the Au-coated grating and the manufactures' calibration curves for the Ir-coated grating and light detectors. Then the wavelength dependence of detection sensitivity was compared with that of a similar VUV-soft x ray detection system which is calibrated using a synchrotron radiation facility available at their laboratory

Discussion and remarks:

At ETL a group of researcher has set up a very active experimental program to investigate the interactions of intense ultrafast laser pulses with rare gases. They have published at least five journal papers in the past three years to inform their findings to the rest of researchers in the world. Their research is more in the area of basic research, rather than applied research at which we are more familiar with many of the MITI sponsored programs. Based on conversation with ETL scientists, I felt ETL is becoming more like U.S. national laboratories in last few years where an increased number of their scientists are engaging more and more in basic research programs. This experimental program is of no exception.

When I was given a tour of their experimental facility, I was surprised to see many modern diagnostic equipment. It was not like the usual Japanese university laboratories. With these modern equipment, Dr Miyazaki and the rest of ETL scientists are really making progress in this new research arena. However, what they are lacking is the theoretical support to analyze their findings in detail.

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